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(54) **ACOUSTICALLY SUMMED REFERENCE MICROPHONE FOR ACTIVE NOISE CONTROL**

(71) Applicant: **Apple Inc.**, Cupertino, CA (US)

(72) Inventors: **Michael B. Howes**, San Jose, CA (US); **Miikka O. Tikander**, Sunnyvale, CA (US)

(73) Assignee: **APPLE INC.**, Cupertino, CA (US)

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H04R 1/10	(2006.01)
G10K 11/178	(2006.01)
H04R 3/00	(2006.01)

(52) **U.S. Cl.**

CPC ***H04R 1/1008*** (2013.01); ***G10K 11/178*** (2013.01); ***G10K 11/1788*** (2013.01); ***H04R 3/005*** (2013.01); *G10K 2210/1081* (2013.01); *H04R 2460/11* (2013.01)

(58) **Field of Classification Search**

CPC .. H04R 1/1008; H04R 3/005; H04R 2460/11; H04R 1/1075; H04R 5/033; G10K 2210/1081; G10K 11/1788; G10K 2210/3045

See application file for complete search history.

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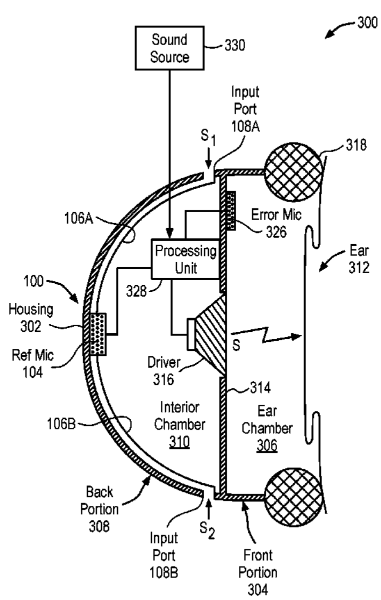
Primary Examiner — Andrew L Sniezek

(74) *Attorney, Agent, or Firm* — Womble Bond Dickinson (US) LLP

(57) **ABSTRACT**

A headphone including a circumaural or supra-aural ear cup having an ear cup housing wall which forms an interior chamber within the ear cup. A transducer is positioned within the interior chamber for producing an acoustic output to a user and an active noise control assembly positioned within the interior chamber. The active noise control assembly including a reference microphone, the reference microphone is acoustically coupled to a plurality of reference input ports spaced around the ear cup housing wall such that a sound input from each of the different spacial locations around the ear cup housing wall is received by the reference microphone and acoustically summed to provide a reference audio signal indicative of the sound input at the different spacial locations. The headphone further including a processing circuit operable to generate an anti-noise signal from the reference audio signal.

17 Claims, 4 Drawing Sheets



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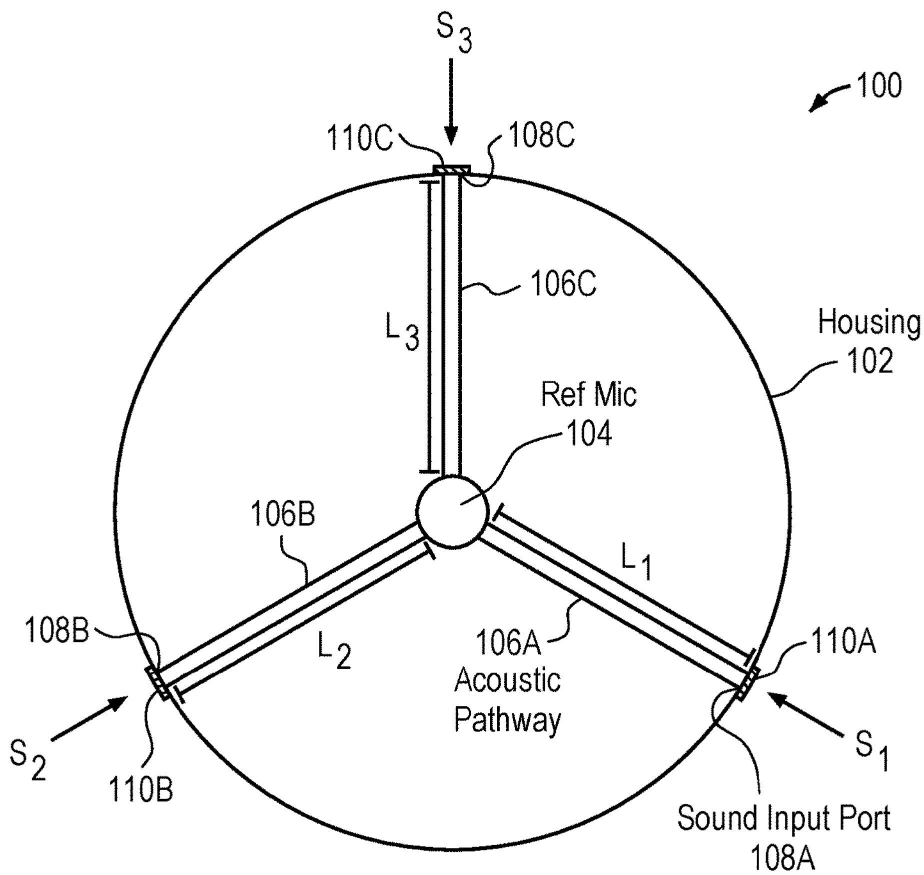
S3
100
110C
108C
106C
L3
Housing
102
Ref Mic
104
106B
L1
L2
108B
110A
106A
Acoustic
Pathway
S2
S1
110B
Sound Input Port
108A

FIG. 1

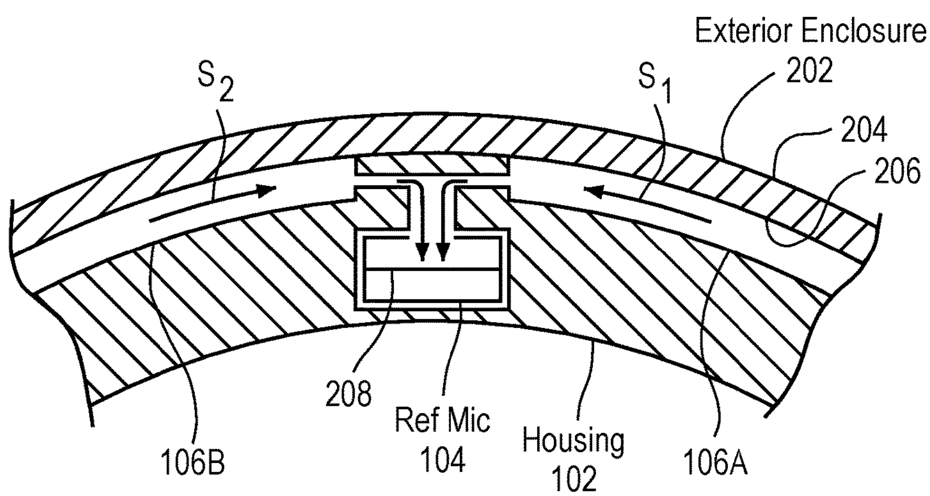
Exterior Enclosure
202
S2
S1
204
206
208
Ref Mic
104
Housing
102
106B
106A

FIG. 2

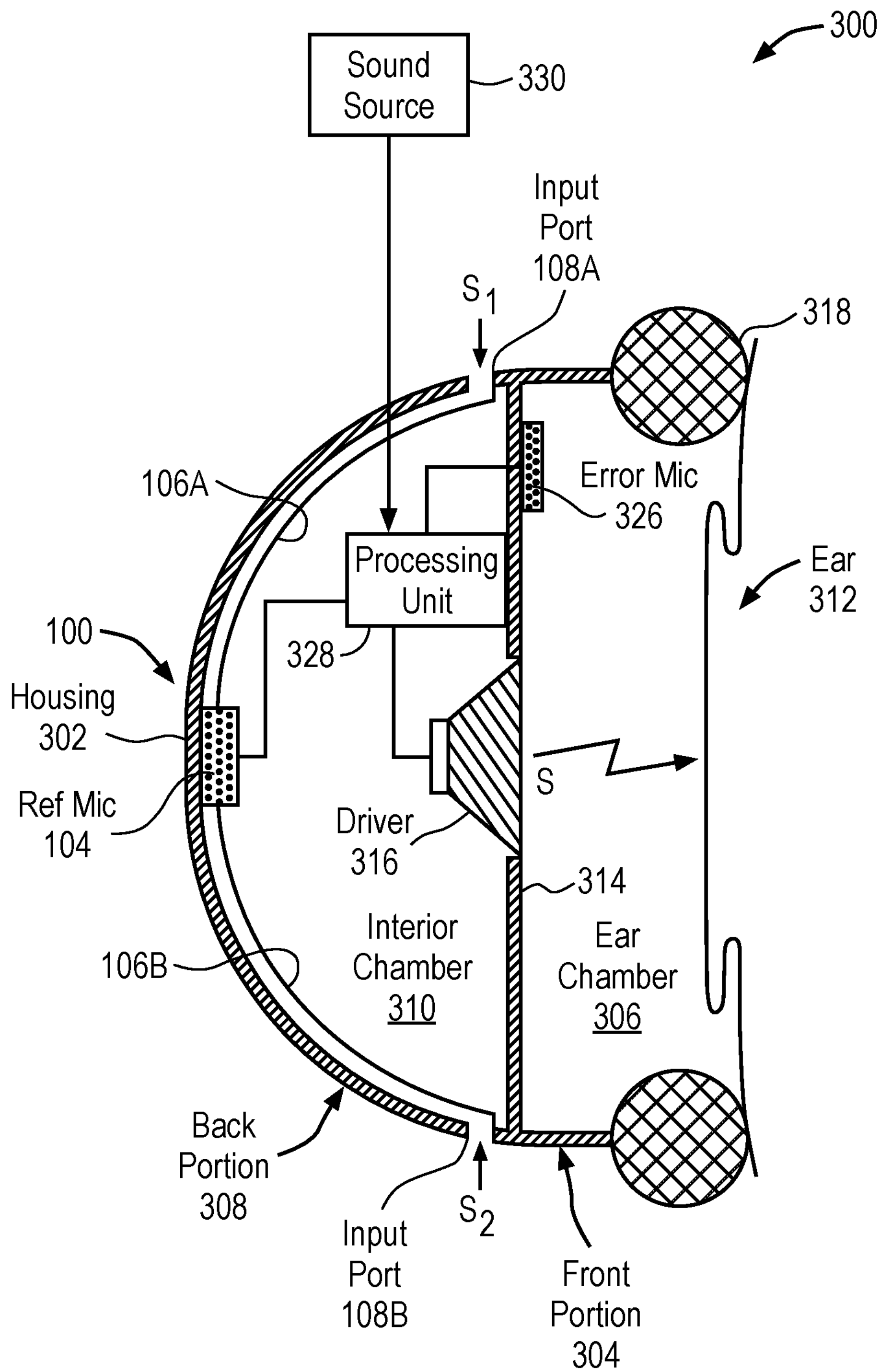
300
Sound Source
330
Input Port 108A
S1
318
Error Mic 326
106A
Processing Unit
Ear 312
100
328
Housing 302
S
Ref Mic 104
Driver 316
314
Interior Chamber 310
Ear Chamber 306
106B
Back Portion 308
S2
Input Port 108B
Front Portion 304

FIG. 3

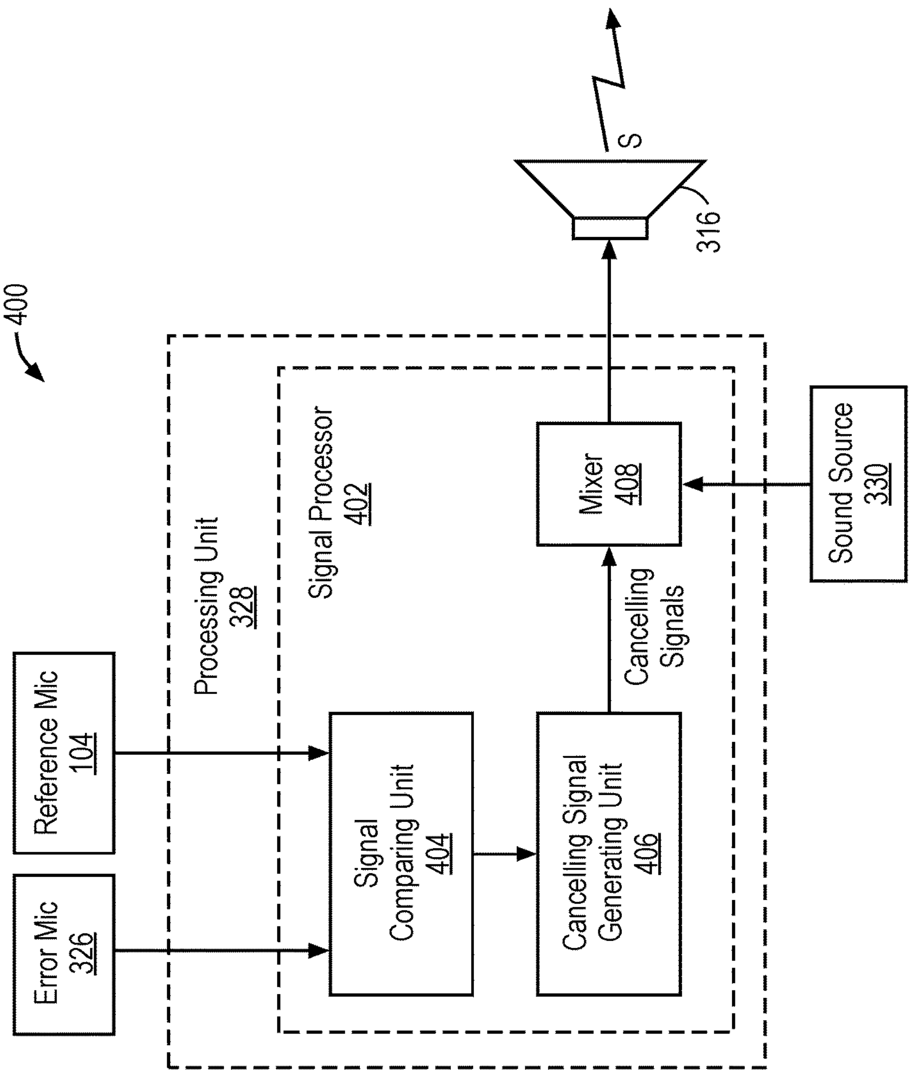
400
Reference Mic
104
Error Mic
326
Processing Unit
328
Signal Processor
402
Signal
Comparing Unit
404
Cancelling Signal
Generating Unit
406
Cancelling
Signals
Mixer
408
Sound Source
330
316
S

FIG. 4

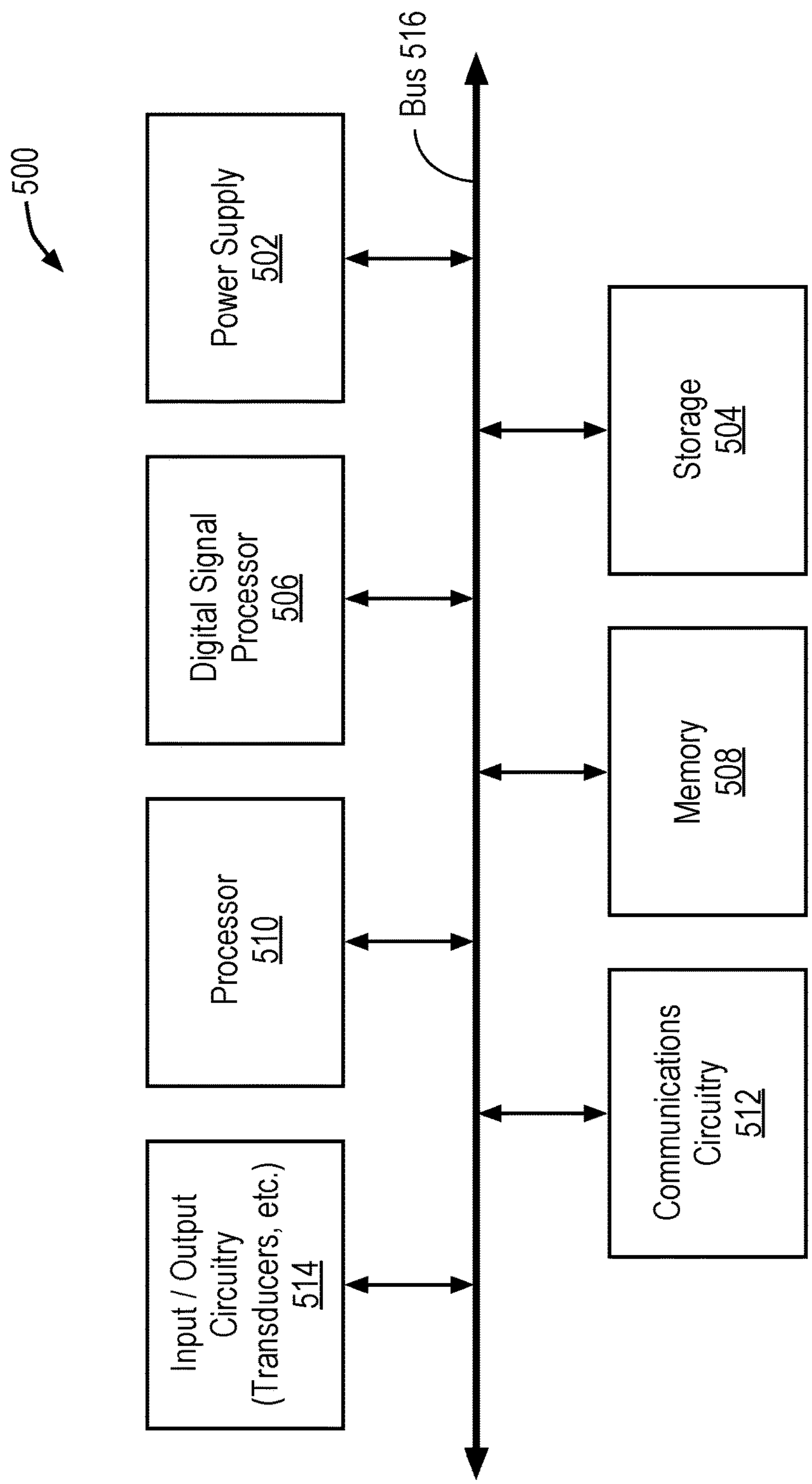
500
Bus 516
Power Supply 502
Digital Signal Processor 506
Processor 510
Input / Output Circuitry (Transducers, etc.) 514
Storage 504
Memory 508
Communications Circuitry 512

FIG. 5

ACOUSTICALLY SUMMED REFERENCE MICROPHONE FOR ACTIVE NOISE CONTROL

FIELD

An embodiment of the invention is directed to a reference microphone adapted for acoustic summation of sounds from different spacial locations around a headphone or headset for active noise control. Other embodiments are also described and claimed.

BACKGROUND

Whether listening to a portable media player while traveling, or to a stereo or theater system at home, consumers often choose headphones. Headphones typically include a pair of ear cups with associated earpads, and are held together by a headband. They can be classified into two general categories based on the size of the ear cups/earpads, namely circumaural (e.g., encompass the ear) or supra-aural (e.g., press against the ear). Both designs have their own acoustic advantages and disadvantages, but in most cases have some form of a passive noise control system or electronic active noise control system for reducing unwanted sounds from interfering with the desired sound output to the user. A passive noise control system may rely on the structure of the ear cup itself to passively or mechanically prevent unwanted noises from entering the ear cup (e.g., ear cup size, clamping force, vent, etc.). An active noise control (ANC) system is a noise (or unwanted sound) cancellation system which can electronically attenuate or cancel noise within the ear cup by, for example, emitting an "anti-noise" signal having the same amplitude and opposite phase to that of the noise such that they cancel each other out. For example, the ANC system may include a reference microphone, a cancelling speaker to output the anti-noise signal and an error microphone. The reference microphone may detect a reference input (e.g., unwanted ambient or environmental sounds), which is in turn used by the ANC system to generate the "anti-noise" signal, and the error microphone may be used to monitor a performance of the ANC system. In cases, however, where the reference input is coming from multiple directions, or a source that is otherwise not near the reference microphone, the reference microphone may not provide an accurate reference signal. To address this issue, multiple reference microphones are sometimes positioned at different spacial locations around the device housing. These discrete microphone signals are then summed electrically and used as a more spatially robust noise reference. Such systems, however, are electrically complex and may be rather costly.

SUMMARY

An embodiment of the invention is directed to a reference microphone for use in an active noise control (ANC) system in which acoustic summation of multiple sound inputs can occur at the reference microphone. Representatively, the assembly may include two or more acoustic input pathways that can receive an acoustic (or sound) input from different directions and/or spacial locations around the reference microphone (or a housing within which the reference microphone is used) and direct the sounds to the reference microphone. The sounds are then acoustically summed at the microphone diaphragm and used to provide a reference audio signal indicative of sounds at various spacial locations around the microphone (or an enclosure within which the microphone is used). The reference audio signal may be equivalent to a reference signal produced by electrical summation using multiple microphones. The reference microphone described herein can therefore achieve a reference signal indicative of sounds (e.g., sound pressures) at multiple locations using only one reference microphone. It is further contemplated that the reference microphone may be used in an ANC system on the down link (far end) signal (e.g., to cancel an unwanted sound on the far end signal at the headphones), as opposed to an up link signal application (e.g., a microphone for ANC within a telephone).

More specifically, in one embodiment, the invention includes a headphone including a circumaural or supra-aural ear cup with an ear cup housing wall that forms an interior chamber within the ear cup. A transducer is positioned within the interior chamber for producing an acoustic output to a user. In addition, the headphone includes an active noise control assembly positioned within the interior chamber. The active noise control assembly may include a reference microphone and an error microphone. The reference microphone may be acoustically coupled to a number of reference input ports spaced around the ear cup housing wall such that a sound input from each of the different spacial locations around the ear cup housing wall is received by the reference microphone and acoustically summed to provide a reference audio signal indicative of the sound input at the different spacial locations. The headphone may also include a processing circuit operable to generate an anti-noise signal from the reference audio signal for countering effects of unwanted ambient sounds in the acoustic output of the transducer. In one embodiment, the reference input ports are open to an ambient environment outside of the ear cup housing wall. In addition, the reference input ports may be evenly spaced around the ear cup housing wall. The reference microphone may be acoustically coupled to the plurality of reference input ports by a plurality of acoustic input pathways extending in different directions from the reference microphone. In some embodiments, the plurality of acoustic input pathways are substantially the same length. In some embodiments, the reference audio signal is substantially equivalent to an electrical summation produced using a plurality of microphones at the different spacial locations around the ear cup housing wall. The reference microphone may be considered an omnidirectional microphone because it can receive sound inputs from different directions. The sound input to the reference microphone from each of the different spacial locations as previously discussed may be received along a single side of a diaphragm within the reference microphone.

In another embodiment, a noise cancelling headphone including an ear cup, a transducer and an active noise control assembly is disclosed. The ear cup may be formed by an ear cup housing wall having an exterior surface to an ambient environment outside of the ear cup and an interior surface defining an interior chamber. The transducer may be positioned within the interior chamber for producing an acoustic output to a user. The active noise control assembly may further be positioned within the interior chamber and include a reference microphone module. The reference microphone module may include a first acoustic input pathway extending in a first direction from a reference microphone within the module to the exterior surface of the ear cup housing wall and a second acoustic input pathway extending in a second direction from the reference microphone to the exterior surface of the ear cup housing wall. The first direction and the second direction are different such that the reference microphone receives an omnidirectional acoustic input that is acoustically summed at the reference microphone. In some cases, the first acoustic input pathway and the second acoustic input pathway are acoustically coupled to a same side of a diaphragm within the reference microphone. In addition, the first acoustic input pathway and the second acoustic input pathway may be acoustically coupled to a first input port and a second input port, respectively, formed through the ear cup housing wall at different spacial locations along the ear cup housing wall. In some embodiments, the headphone may include a third acoustic input pathway extending in a third direction from the reference microphone to the exterior surface of the ear cup housing wall, and the third direction is different from the first direction and the second direction. The third acoustic input pathway may be acoustically coupled to a third input port formed through the ear cup housing wall, and the first input port, the second input port and the third input port are at substantially evenly spaced locations around the ear cup housing wall.

In other embodiments, a reference microphone assembly for an active noise control system is disclosed. The reference microphone assembly may include a housing and a reference microphone mounted to the housing. The housing may have a first acoustic input pathway and a second acoustic input pathway. The first acoustic input pathway may be configured to receive a first sound input from a first direction and the second acoustic input pathway may be configured to receive a second sound input from a second direction different than the first direction. The reference microphone may be acoustically coupled to the first acoustic input pathway and the second acoustic input pathway such that the reference microphone receives the first sound input and the second sound input, and the first sound input and the second sound input are acoustically summed at the reference microphone. In some embodiments, a sound input port to the first acoustic input pathway faces a different direction than a sound input port to the second acoustic input pathway. In addition, the first acoustic input pathway and the second acoustic input pathway may be acoustically coupled to different sound input ports in a headphone ear cup housing wall. In still further embodiments, the housing is coupled to an interior surface of an ear cup housing wall of a headphone, and the first acoustic input pathway is acoustically coupled to a first sound input port formed through the ear cup housing wall and the second acoustic input pathway is acoustically coupled to a second sound input port formed through the ear cup housing wall. In some cases, the first acoustic input pathway and the second acoustic input pathway may be substantially the same length. The microphone module may also include a third acoustic input pathway configured to receive a third sound input from a third direction, wherein the third direction is different than the first direction and the second direction. The reference microphone may be operable to generate a reference audio signal indicative of the acoustically summed sound input for use in an active noise control system.

The above summary does not include an exhaustive list of all aspects of the present invention. It is contemplated that the invention includes all systems and methods that can be practiced from all suitable combinations of the various aspects summarized above, as well as those disclosed in the Detailed Description below and particularly pointed out in the claims filed with the application. Such combinations have particular advantages not specifically recited in the above summary.

BRIEF DESCRIPTION OF THE DRAWINGS

The embodiments are illustrated by way of example and not by way of limitation in the figures of the accompanying drawings in which like references indicate similar elements. It should be noted that references to "an" or "one" embodiment in this disclosure are not necessarily to the same embodiment, and they mean at least one.

FIG. **1** illustrates a top view schematic diagram of one embodiment of a reference microphone assembly.

FIG. **2** illustrates a side view schematic diagram of the reference microphone assembly of FIG. **1** coupled with an exterior housing.

FIG. **3** illustrates a side view schematic diagram of the reference microphone assembly of FIG. **1** implemented within an ear cup.

FIG. **4** illustrates a block diagram showing one embodiment of an operation of a noise control assembly.

FIG. **5** is a simplified logic flow chart of an illustrative mode of operation in accordance with one embodiment of an active noise control assembly.

DETAILED DESCRIPTION

In this section we shall explain several preferred embodiments of this invention with reference to the appended drawings. Whenever the shapes, relative positions and other aspects of the parts described in the embodiments are not clearly defined, the scope of the invention is not limited only to the parts shown, which are meant merely for the purpose of illustration. Also, while numerous details are set forth, it is understood that some embodiments of the invention may be practiced without these details. In other instances, well-known structures and techniques have not been shown in detail so as not to obscure the understanding of this description.

FIG. **1** illustrates a top view schematic diagram of one embodiment of a reference microphone assembly. Reference microphone assembly **100** may include a housing **102** and a reference microphone **104** mounted to housing **102**. Housing **102** may be any type of enclosure to which the reference microphone **104** and its associated components can be mounted or enclosed within. For example, in one embodiment, housing **102** may be a reference microphone module within which the reference microphone is mounted, and which can then be used to mount the reference microphone within the desired audio device. In another embodiment, housing **102** may be an enclosure for an audio device within which the reference microphone **104** is used, for example an ear cup housing. Reference microphone **104** may be any type of acoustic-to-electric transducer or sensor that converts sound into an electrical signal. In this aspect, although not explicitly shown, reference microphone **104** may include, for example, a sound pick up surface (e.g., a diaphragm), a moving coil and magnet assembly, or may be a MEMS microphone. In addition, it should be understood that reference microphone **104** is referred to as a "reference" microphone because it is intended to be used to pick up sounds (e.g., unwanted sounds) and produce a reference signal indicative of those sounds for use within an ANC system.

More specifically, reference microphone **104** may sample sounds, or otherwise pick up a sound reference signal, indicative of sound pressures at multiple locations around housing **102** and provide an acoustic summation of those sounds for use by the ANC system. Representatively, housing **102** may include a number of acoustic pathways **106**A, **106**B and **106**C extending from reference microphone **104** to a number of acoustic input ports **108**A, **108**B and **108**C formed through an exterior surface of housing **102**. In one embodiment, acoustic input ports **108A-108**C may be open to an ambient environment outside of housing **102** such that they can be used to detect unwanted ambient sounds (e.g., noise). Acoustic input ports **108**A-**108**C may further be positioned at different spacial locations around housing **102** such that sounds S_1, S_2 and S_3 at these different locations can be sampled by reference microphone **104**. For example, acoustic input ports **108**A-**108**C could be at locations around housing **102** where three reference microphones would be positioned in a multiple reference microphone ANC system. Representatively, in one embodiment, acoustic input ports **108**A-**108**C may be evenly spaced around an exterior surface of housing **102**. Other configurations, however, are also contemplated. For example, acoustic input ports **108**A-**108**C may be at different locations around housing **102** but unevenly spaced, or depending upon a shape of housing **102**, along different sides of housing **102**.

In addition, in some embodiments, each of acoustic input ports **108**A-**108**C may face different directions such that they can pick up omnidirectional sounds S_1-S_3 (e.g., sounds traveling in different directions as illustrated by the arrows). For example, each of sounds S_1-S_3 may originate from sound sources at different locations around housing **102**, and therefore travel toward housing **102** in different directions. Since each of acoustic input ports **108**A-**108**C face the direction of the respective sound sources, they can more directly pick up sounds S_1-S_3 from these sources. In this aspect, reference microphone **104** may also be referred to as an omnidirectional microphone in that it can pick up sounds coming from various directions. It should further be understood that, in some embodiments, the direction in which sounds S_1-S_3 travel is toward a side of reference microphone **104**, as opposed toward an acoustic pick-up surface (e.g., diaphragm) of reference microphone **104**. Acoustic input ports **108**A-**108**C may have any size and shape suitable for picking up sounds S_1-S_3. In addition, although three acoustic input ports **108**A-**108**C are illustrated, it is contemplated that any number of acoustic input ports **108**A-**108**C may be used, for example, housing **102** may have at least two or more acoustic input ports.

In addition, in some embodiments, a damping member may be associated with one or more of acoustic input ports **108**A-**108**C and/or acoustic input pathways **106**A-**106**C to address possible resonances in the pathways. Representatively, in one embodiment, damping members **110**A, **110**E and **110**C are positioned over each of acoustic input ports **108**A, **108**B and **108**C, respectively. In this aspect, damping members **110**A-**110**C may be made of an acoustic mesh sufficient to achieve damping at higher frequencies without interfering with ANC operations (e.g., frequencies less than 3 kHz). In other embodiments, the damping members may be made of a porous material such as a cloth or foam that is positioned inside of each of acoustic input pathways **106**A-**106**C. For example, the porous cloth or foam material may completely fill each of acoustic input pathways **106**A-**106**C to completely eliminate all resonances.

As previously discussed, acoustic input pathways **106**A-**106**C may extend from reference microphone **104** to each of acoustic input ports **108**A-**108**C, respectively. In this aspect, sounds S_1-S_3 entering acoustic input ports **108**A-**108**C travel through acoustic input pathways **106**A-**106**C to reference microphone **104**. In some embodiments, each of acoustic input pathways **106**A-**106**C may have an acoustic length L_1, L_2, and L_3, respectively. In other words, acoustic input pathways **106**A-**106**C are not simply holes, but rather pathways having a defined acoustic length along which sound must travel to reach reference microphone **104**. Each of acoustic lengths L_1-L_3 may be acoustically the same. It is contemplated, however, that in some embodiments where it is known that certain sounds sources are closer/farther than others, one or more of acoustic lengths L_1-L_3 of acoustic input pathways **106**A-**106**C may be different to accommodate these sound sources at known locations (e.g., an acoustic input pathway aligned with a closer sound source may be shorter than the others). In addition, as shown in FIG. **1**, each of acoustic input pathways **106**A-**106**C may extend in different directions from reference microphone **104**. For example, each of acoustic input pathways **106**A-**106**C may extend toward, and connect to, acoustic input ports **108**A-**108**C in different sides of housing **102**. In this aspect, in one embodiment, each of acoustic input pathways **106**A-**106**C form an angle with respect to one another and are otherwise not parallel with one another.

The sounds S_1-S_3 input to reference microphone **104** from the different spacial locations around housing **102** as previously discussed can then be combined at the sound pick-up surface (e.g., diaphragm) within microphone **104** and acoustically summed to produce a reference signal indicative of sounds (e.g., unwanted background noises) sampled from multiple locations for ANC. Reference microphone assembly **100** therefore allows for a more spacially robust reference signal for ANC than that which is typically achieved using a single reference microphone (which samples sound from a single location), without the need for multiple reference microphones. It should further be understood that reference microphone **104** with multiple input pathways for multi-sound input as disclosed herein is operable within a desired frequency range for ANC (e.g., up to about 2 kHz).

FIG. **2** illustrates a side view schematic diagram of the reference microphone assembly of FIG. **1** coupled with an exterior housing. In particular, in this embodiment, housing **102** and reference microphone **104** are shown mounted within an exterior enclosure **202**. Exterior enclosure **202** may, for example, be an ear cup enclosure for a headphone device. In this aspect, exterior enclosure **202** may have a cosmetic exterior surface **204** and an interior surface **206** that forms an interior chamber within which housing **102** and reference microphone **104** of reference microphone assembly **100** are positioned. Reference microphone **104** is further shown mounted within housing **102**. From this view, it can be seen that when housing **102** is mounted to the interior surface **206** of exterior enclosure **202**, acoustic pathways **106**A and **106**B are positioned between housing **102** and exterior enclosure **202** and provide an acoustic pathway for sound S_1 and S_2 to travel to reference microphone **104**. In addition, it can be seen that sound S_1 and S_2 are both input to the same sound pick-up face of diaphragm **208** such that they can be acoustically summed within an acoustic domain of reference microphone **104**.

FIG. **3** illustrates a side view schematic diagram of the reference microphone assembly of FIG. **1** implemented within an ear cup. In particular, microphone assembly **100** is shown positioned within ear cup **300**. Ear cup **300** may be a left or right ear cup of a headphone assembly, and may be circumaural or supra-aural as previously discussed. Ear cup **300** includes ear cup housing wall **302**, which forms an enclosure dimensioned to encircle and/or cover a user's ear. Ear cup housing wall **302** may include a front portion **304** defining an ear chamber **306** and a back portion **308** defining an interior chamber **310** within ear cup **300**. Ear chamber **306** may surround the ear **312** when ear cup **300** is positioned on the user's head. In some cases, an earphone pad **318** may be positioned around front portion **304** of ear cup housing wall **302** to ensure a comfortable fit around the user's ear. Interior chamber **310** may be a substantially closed chamber positioned behind the ear chamber **306** (as viewed in FIG. **3**). Interior chamber **310** may be separated from ear chamber **306** by mid wall **314**.

A transducer or driver **316** for outputting a music signal (S) in a direction of ear **312** may be mounted within mid wall **314**. Driver **316** may be any type of electric-to-acoustic transducer having a pressure sensitive diaphragm and circuitry configured to produce a sound in response to an electrical audio signal input (e.g., a loudspeaker). The electrical audio signal may be a music signal input to driver **316** by sound source **330**. Sound source **330** may be any type of audio device capable of outputting an audio signal, for example, an audio electronic device such as a portable music player, home stereo system or home theater system capable of outputting an audio signal.

In order to improve an acoustic performance of ear cup **300**, an ANC assembly including reference microphone assembly **100** may be positioned within ear cup **300**. The ANC assembly may include any type of active noise cancelling system capable of emitting a cancelling or anti-noise signal for cancelling noise within ear cup **300**. For example, active noise control assembly may be a feedback and/or feedforward ANC system. Representatively, in one embodiment, the ANC assembly may include reference microphone assembly **100** including reference microphone **104** for detecting unwanted background sounds and an error microphone **326** for detecting sounds within ear chamber **306**. As shown in FIG. **3**, reference microphone assembly **100** may be positioned within interior chamber **310** and acoustically coupled to acoustic input ports **108**A, **108**B at different locations along ear cup housing wall **302**. For example, reference microphone **104** may be positioned near a center of ear cup housing wall and acoustically coupled to input ports **108**A, **108**B formed through ear cup housing wall **302** (near ear pads **318**) via acoustic input pathways **106**A, **106**B. In this aspect, sounds S_1 and S_2 (e.g., unwanted backrounds sounds) at various locations around ear cup housing **302** can be detected and input to reference microphone **104** for acoustic summation as previously discussed.

Similar to reference microphone **104**, error microphone **326** may be any type of acoustic-to-electric transducer or sensor having a pressure sensitive diaphragm and circuitry capable of converting ear cup sounds into an electrical signal (e.g., a MEMS microphone). Error microphone **326** may mounted within ear chamber **306** so that it can detect sounds that could be heard by a user and interfere with the listening experience. The ear cup sounds detected by error microphone **326** may then be converted to an ear cup noise electrical signal and transmitted to processing unit **328**. Processing unit **328** may then process both the ear cup noise electrical signal and the reference signal from reference microphone **104** to determine whether ANC is necessary. Where ANC is necessary, processing unit **328** will generate a cancelling or anti-noise signal having an amplitude equal to, but of a different phase than, the ear cup sounds to be cancelled. The cancelling signal will then be transmitted from processing unit **328** to driver **316**, which in turn, outputs the cancelling signal to ear chamber **306** so that any undesired ear cup sound is cancelled before reaching the user's ear. The cancelling signal may be transmitted along with, or separate from, a music signal (S) transmitted to driver **316** by sound source **330** for output to the user.

FIG. **4** illustrates a block diagram showing one embodiment of an operation of an active noise control assembly. Active noise control assembly **400** may include processing unit **328**, which includes various processing components configured to drive the operation of the active noise control assembly as will now be described in more detail. In one embodiment, processing unit **328** may include a signal processor **402**, which may in some embodiments be a digital signal processor (DSP). Signal processor **402** may include various signal processing components, including but not limited to, a signal comparing unit **404**, a cancelling signal generating unit **406** and a mixer **408** for processing of the reference electrical signals from reference microphone **104** and/or electrical signals from error microphone **326**. Representatively, during an operation of ear cup **300**, signal comparing unit **404** can compare the acoustically summed reference signal from reference microphone **104**, the electrical signals from error microphone **326** and/or music sound signals (S) to each other and/or a threshold value, to determine whether ANC is necessary. Where ANC is necessary, instructions may then be sent to cancelling signal generating unit **406** to generate a cancelling signal or anti-noise signal sufficient to cancel any unwanted sounds. The cancelling signals generated by cancelling signal generating unit **406** may then be sent to mixer **408**. The cancelling signal output by cancelling signal generating unit **406** may be synthesized with the musical signal (S) input by sound source **330** and sent to driver **316** for output to the user (see FIG. **3**).

Although not illustrated in FIG. **4**, it is to be understood that, a battery or other power source for ANC assembly **400** may be included within the associated headphone. It is further to be understood that ANC assembly **400** is shown generically in FIG. **4** for clarity. Persons skilled in the art can, however, appreciate that any one or more of the components discussed herein can be omitted, modified, combined, and/or rearranged, and any additional processing components and/or circuitry necessary for processing of sound electrical signals and operation of an ANC assembly may be included without departing from the scope of the invention. Representative components and/or circuitry that may be included but are not illustrated in FIG. **4** may include, but are not limited to, amplifiers, filters, phase adjusters, signal converters, memory, additional processors and the like. It is further to be understood that in some embodiments, each of the components and/or circuitry of processing unit **328** are integrated within ear cup **300** (of the associated headphone in general) such that the signal processing and operating decisions take place within ear cup **300**. In other embodiments, one or more components of processing unit **328** may be integrated within an electronic device remote to ear cup **300** such that signal processing and/or operating decisions are performed outside of ear cup **300** and the operating instructions are transferred to ear cup **300** (e.g., via a wire or wirelessly) for execution. For example, processing unit **328** (including, for example, signal comparing unit **404**, cancelling signal generating unit **406** and mixer **408**) may be integrated within sound source **330** or a chip configured to collect noise electrical signals, process the signals and transfer the signals, in some cases along with instructions, to a host device.

FIG. **5** illustrates a simplified schematic view of one embodiment of an electronic device in which an active noise control assembly may be implemented. For example, ear cup **300** (including the associated headphone assembly) is an example of a system that can include some or all of the circuitry illustrated by electronic device **500**.

Electronic device **500** can include, for example, power supply **502**, storage **504**, signal processor **506**, memory **508**, processor **510**, communication circuitry **512**, and input/output circuitry **514**. In some embodiments, electronic device **500** can include more than one of each component of circuitry, but for the sake of simplicity, only one of each is shown in FIG. **5**. In addition, one skilled in the art would appreciate that the functionality of certain components can be combined or omitted and that additional or less components, which are not shown in FIGS. **1-4**, can be included in, for example, ear cup **300**.

Power supply **502** can provide power to the components of electronic device **500**. In some embodiments, power supply **502** can be coupled to a power grid such as, for example, a wall outlet. In some embodiments, power supply **502** can include one or more batteries for providing power to an ear cup, headphone or other type of electronic device associated with the headphone. As another example, power supply **502** can be configured to generate power from a natural source (e.g., solar power using solar cells).

Storage **504** can include, for example, a hard-drive, flash memory, cache, ROM, and/or RAM. Additionally, storage **504** can be local to and/or remote from electronic device **500**. For example, storage **504** can include integrated storage medium, removable storage medium, storage space on a remote server, wireless storage medium, or any combination thereof. Furthermore, storage **504** can store data such as, for example, system data, user profile data, and any other relevant data.

Signal processor **506** can be, for example a digital signal processor, used for real-time processing of digital signals that are converted from analog signals by, for example, input/output circuitry **514**. After processing of the digital signals has been completed, the digital signals could then be converted back into analog signals. For example, the signal processor **506** could be used to analyze digitized audio signals received from reference or error microphones to determine how much of the audio signal is ambient noise or ear cup noise and how much of the audio signal is, for example, music signals.

Memory **508** can include any form of temporary memory such as RAM, buffers, and/or cache. Memory **508** can also be used for storing data used to operate electronic device applications (e.g., operation system instructions).

In addition to signal processor **506**, electronic device **500** can additionally contain general processor **510**. Processor **510** can be capable of interpreting system instructions and processing data. For example, processor **510** can be capable of executing instructions or programs such as system applications, firmware applications, and/or any other application. Additionally, processor **510** has the capability to execute instructions in order to communicate with any or all of the components of electronic device **500**. For example, processor **510** can execute instructions stored in memory **508** to enable or disable ANC.

Communication circuitry **512** may be any suitable communications circuitry operative to initiate a communications request, connect to a communications network, and/or to transmit communications data to one or more servers or devices within the communications network. For example, communications circuitry **512** may support one or more of Wi-Fi (e.g., a 802.11 protocol), Bluetooth®, high frequency systems, infrared, GSM, GSM plus EDGE, CDMA, or any other communication protocol and/or any combination thereof.

Input/output circuitry **514** can convert (and encode/decode, if necessary) analog signals and other signals (e.g., physical contact inputs, physical movements, analog audio signals, etc.) into digital data. Input/output circuitry **514** can also convert digital data into any other type of signal. The digital data can be provided to and received from processor **510**, storage **504**, memory **508**, signal processor **506**, or any other component of electronic device **500**. Input/output circuitry **514** can be used to interface with any suitable input or output devices, such as, for example, reference microphone **104**, error microphone **326** or sound source **330** of FIGS. **1-3**. Furthermore, electronic device **500** can include specialized input circuitry associated with input devices such as, for example, one or more proximity sensors, accelerometers, etc. Electronic device **500** can also include specialized output circuitry associated with output devices such as, for example, one or more speakers, earphones, etc.

Lastly, bus **516** can provide a data transfer path for transferring data to, from, or between processor **510**, storage **504**, memory **508**, communications circuitry **512**, and any other component included in electronic device **500**. Although bus **516** is illustrated as a single component in FIG. **5**, one skilled in the art would appreciate that electronic device **500** may include one or more components.

While certain embodiments have been described and shown in the accompanying drawings, it is to be understood that such embodiments are merely illustrative of and not restrictive on the broad invention, and that the invention is not limited to the specific constructions and arrangements shown and described, since various other modifications may occur to those of ordinary skill in the art. For example, the ANC system including reference microphone as described herein may be used to improve an acoustic response of any type of earpiece with acoustic capabilities, for example, earbuds, earphones, intra-canal earphones, intra-concha earphones or a mobile phone headset. The description is thus to be regarded as illustrative instead of limiting.

What is claimed is:

1. A headphone comprising:

a circumaural or supra-aural ear cup having an ear cup housing wall which forms an interior chamber within the ear cup;

a transducer positioned within the interior chamber for producing an acoustic output to a user;

an active noise control assembly positioned within the interior chamber, the active noise control assembly comprising a reference microphone, wherein the reference microphone is acoustically coupled to at least three reference input ports arranged at different spatial locations around the ear cup housing wall and facing at least three different directions, respectively, each direction being perpendicular to a direction faced by a sound pick-up surface of the reference microphone, and wherein a sound input from each of the different spatial locations around the ear cup housing wall is received by the reference microphone and acoustically summed to provide a reference audio signal indicative of the sound input at the different spatial locations; and

a processing circuit operable to generate an anti-noise signal from the reference audio signal for countering effects of unwanted ambient sounds in the acoustic output of the transducer.

2. The headphone of claim **1** wherein the reference input ports are open to an ambient environment outside of the ear cup housing wall.

3. The headphone of claim **1** wherein a space between each of the reference input ports arranged around the ear cup housing wall is the same.

4. The headphone of claim **1** wherein the reference microphone is directly connected to the reference input ports by a plurality of acoustic input pathways having portions extending in different directions from the reference microphone.

5. The headphone of claim **4** wherein the different directions are in a radial direction extending from a side of the reference microphone to the earcup housing wall, and the plurality of acoustic input pathways comprise substantially a same length.

6. The headphone of claim **1** wherein the reference audio signal is substantially equivalent to an electrical summation produced using a plurality of microphones at the different spatial locations around the ear cup housing wall.

7. The headphone of claim **1** wherein the reference microphone is an omnidirectional microphone.

8. The headphone of claim **1** wherein the sound input from each of the different spatial locations is received by the sound pick-up surface within the reference microphone.

9. A noise cancelling headphone comprising:

an ear cup formed by an ear cup housing wall, the ear cup housing wall having an exterior surface exposed to an ambient environment outside of the ear cup and an interior surface defining an interior chamber;

a transducer positioned within the interior chamber for producing an acoustic output to a user; and

an active noise control assembly positioned within the interior chamber, the active noise control assembly comprising a reference microphone module, the reference microphone module having a reference microphone mounted to a module wall, the module wall in combination with the interior surface of the earcup housing wall forms at least a first acoustic input pathway, a second acoustic input pathway and a third acoustic input pathway, the first acoustic input pathway extending in a first radial direction from the reference microphone to a first input port through the exterior surface of the ear cup housing wall, the second acoustic input pathway extending in a second radial direction from the reference microphone to a second input port through the exterior surface of the ear cup housing wall, and the third acoustic input pathway extending in a third radial direction from the reference microphone to a third input port through the exterior surface of the ear cup housing wall, wherein the first radial direction, the second radial direction, and the third radial direction are different, and at least the first input port, the second input port, and the third input port are at evenly spaced locations around the ear cup housing wall, such that the reference microphone receives an omnidirectional acoustic input that is acoustically summed at the reference microphone.

10. The headphone of claim **9** wherein the first radial direction and the second radial direction are perpendicular to a direction faced by a sound pick-up surface of the reference microphone, and the first acoustic input pathway and the second acoustic input pathway are acoustically coupled to the sound pick-up surface within the reference microphone.

11. The headphone of claim **9** wherein the first acoustic input pathway and the second acoustic input pathway are acoustically coupled to the first input port and the second input port, respectively, formed through the ear cup housing wall at different spatial locations along the ear cup housing wall and which are radially outward to the reference microphone.

12. A reference microphone assembly for an active noise control system, the microphone assembly comprising:

a housing having a first acoustic input pathway, a second acoustic input pathway and a third acoustic input pathway, each of the first, second and third acoustic input pathways having a length dimension defined by a surface interior to the housing, and each length dimension being substantially the same, wherein the first acoustic input pathway is configured to receive a first sound input from a first direction, the second acoustic input pathway is configured to receive a second sound input from a second direction different than the first direction, and the third acoustic input pathway is configured to receive a sound input from a third direction different than the first direction and the second direction; and

a reference microphone mounted to the housing, the reference microphone is acoustically coupled to the first acoustic input pathway, the second acoustic input pathway, and the third acoustic input pathway and comprises a sound pick-up surface that faces a direction different than the first direction, the second direction and the third direction, and receives the first sound input, the second sound input, and the third sound input, and wherein the first sound input, the second sound input and the third sound input are acoustically summed at the reference microphone.

13. The microphone assembly of claim **12** wherein a sound input port to the first acoustic input pathway faces a different direction than a sound input port to the second acoustic input pathway.

14. The microphone assembly of claim **12** wherein the first acoustic input pathway and the second acoustic input pathway are connected at one end to the reference microphone, and at another end to different sound input ports in a headphone ear cup housing wall.

15. The microphone assembly of claim **12** wherein the housing is coupled to an interior surface of an ear cup housing wall of a headphone, and wherein the first acoustic input pathway is acoustically coupled to a first sound input port formed through the ear cup housing wall, the second acoustic input pathway is acoustically coupled to a second sound input port formed through the ear cup housing wall, and the third acoustic input pathway is acoustically coupled to a third sound input port formed through the earcup housing wall.

16. The microphone assembly of claim **12** wherein the first acoustic input pathway and the second acoustic input pathway are substantially the same length.

17. The microphone assembly of claim **12** wherein the reference microphone is operable to generate a reference audio signal indicative of the acoustically summed sound input for use in an active noise control system.

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